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(54) Carrier recovery in a digital radio link between a fixed and a mobile radio unit

(57) In a radio receiver, a Wiener filter can be applied to give optimum estimates of the complex fading signal characteristic from noisy measurements. It relies on knowledge of the noise level and the auto correlation characteristics of the fading signal. Ideally a different Wiener filter should be used for every different fading characteristic which, for a mobile radio link, depends primarily on the speed of the mobile unit. The present invention provides a set of Wiener filters which are used over a range of speeds combined with a method of selecting the best filter to use in any given case without the knowledge of vehicle speed.

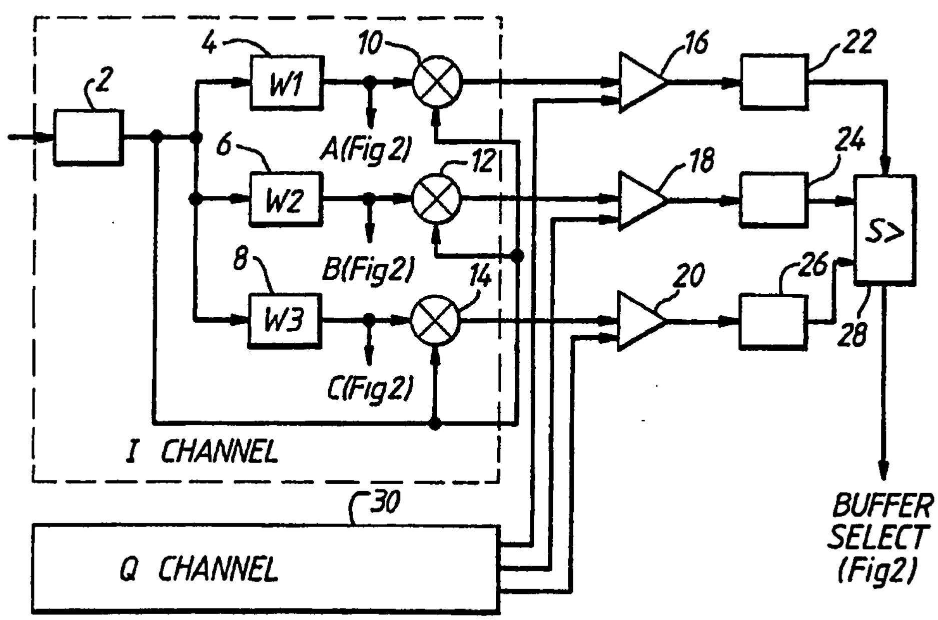

Fig.1

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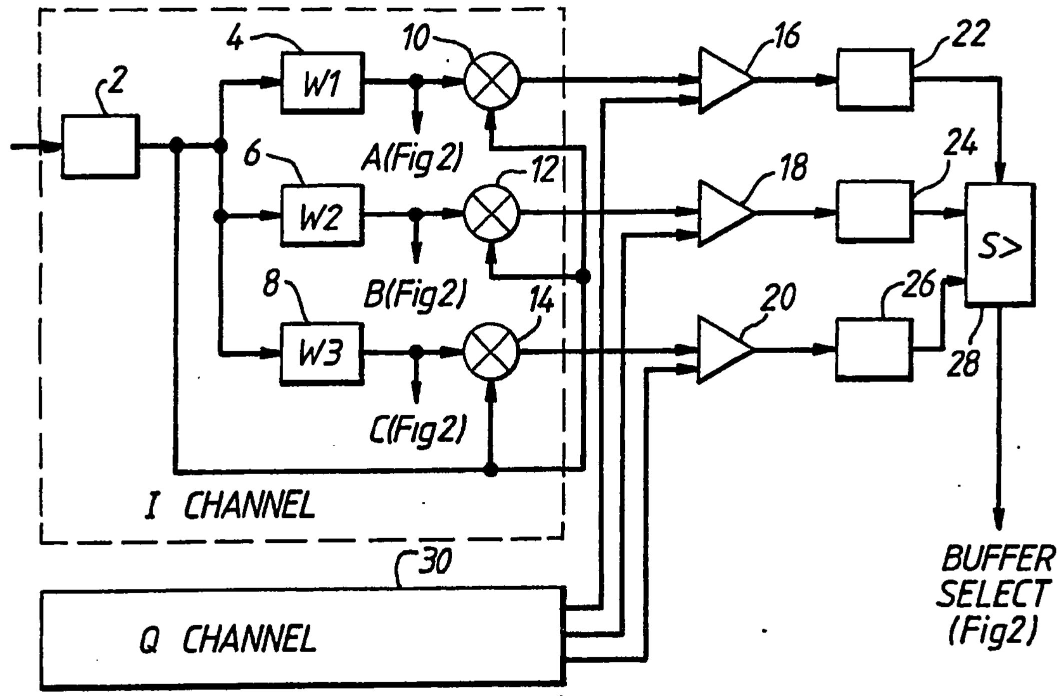
2
4
W1
10
A(Fig2)
6
W2
12
B(Fig2)
8
W3
14
C(Fig2)
I CHANNEL
30
Q CHANNEL
16
18
20
22
24
26
S>
28
BUFFER SELECT (Fig2)

Fig.1

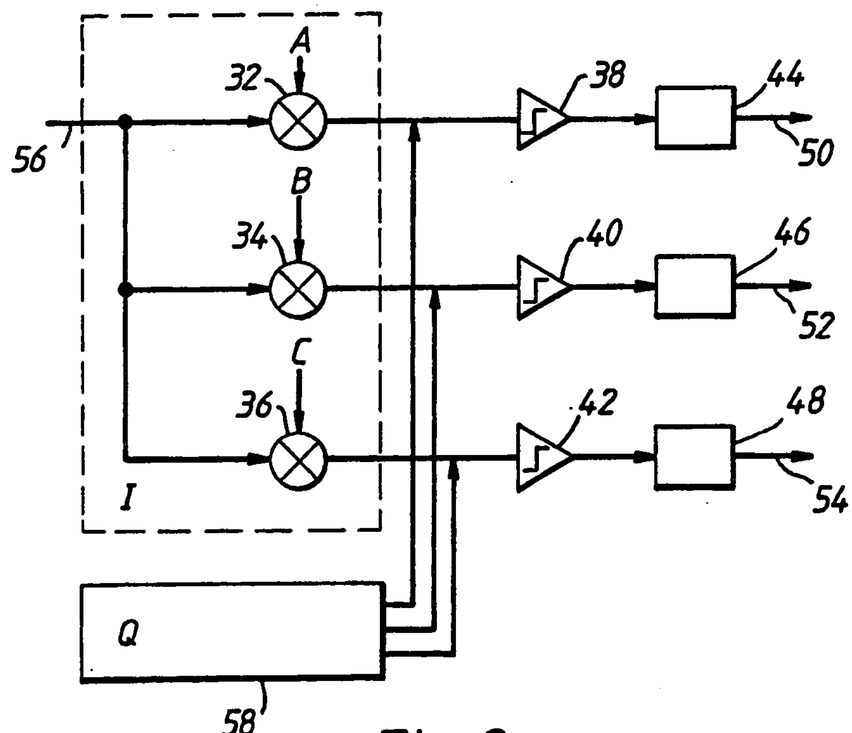
A
32
B
34
C
36
56
I
Q
58
38
40
42
44
46
48
50
52
54

Fig.2

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APPARATUS FOR USE IN EQUIPMENT PROVIDING A DIGITAL RADIO LINK BETWEEN A FIXED AND A MOBILE RADIO UNIT

The present invention relates to apparatus for use in equipment providing a digital radio link between a fixed and mobile radio unit using a modulation type scheme requiring an estimate of a carrier.

In such equipment a conventional approach to carrier recovery involves the use of a phase lock loop. This has a disadvantage in that it has inherent delay. This means that the estimate of phase produced can be out of date for rapidly fading channels. This effect can only be minimised by widening the loop bandwidth. This, in turn, allows in more noise making the estimate obtained less useful for decoding. It would be possible, to some extent, to compensate this delay by inserting a delay in the signal path. However, the delay is a non linear function of frequency and could never be compensated exactly.

An alternative to using the phase lock loop is to use a Wiener filter. Such a filter is able to provide extremely good estimates of the amplitudes of the In Phase (I) and Quadrature (Q) components of, for example, the data signal or a pilot signal provided specifically for the purpose of providing a carrier estimate. Such a time continuous pilot could generally only be incorporated into a modulation scheme employing direct sequence spread spectrum. A Wiener filter is a finite impulse response

(FIR) filter consisting of a tap delay line with the taps feeding a summing junction via multipliers which apply weighting to the taps according to the coefficient as calculated. One example of a Wiener filter is a one step predictor filter and can conveniently be used to give a channel estimate suitable for use in a radio communications system having mobile users. The channel estimate may be derived from a pilot signal or a data modulated signal.

The Wiener filter performs minimum mean square error estimation of the process, in this case fading, given the received samples and knowledge or estimates of the correlation properties of the process and the correlation between the process and the received samples.

In general these correlation processes for estimating the fading channel are related to the received signal to noise ratio and the doppler bandwidth which is determined by the vehicle speed of the mobile user. The actual value of these parameters are unknown, particularly the speed is not known within the receive function.

The purpose of this invention is to provide near optimal filtering based upon sub-optimal knowledge of the parameters.

Ideally, a Wiener filter using different coefficient values should be used for every different fading characteristic, which for a mobile radio link, depends primarily on the speed of the mobile user.

The use of a different set of Wiener parameters for each different fading characteristic would prove costly and may increase complexity through the need to determine the required parameters at any given time.

An object of the present invention is to provide apparatus having a minimum number of Wiener-like filters while giving a performance suitable for use over a wide range of vehicle speeds.

According to the present invention there is provided apparatus for use in equipment providing a digital radio link between a fixed and mobile radio unit, said apparatus comprising correlator means arranged to receive an input signal, a plurality of Wiener filters arranged to receive an output signal from the correlator means, said filters being adapted by scaling means to provide optimum estimation over a set of contiguous ranges of vehicular speed, enabling each filter to be responsive to a different range of speed of the mobile unit, and selection means for selecting which Wiener filter is to be used to maintain a radio link between the fixed and mobile unit in dependence upon the speed of the mobile unit.

An embodiment of the present invention will now be described with reference to the accompanying drawings, wherein:

Figure 1 shows apparatus for use in equipment to provide a digital radio link between a fixed and a mobile radio unit, and:

Figure 2 shows apparatus for handling digital data via the digital radio link.

Referring to Figure 1, there is shown an input device 2 which may be in the form of a pilot correlator, arranged to receive a real component of a complex input signal. The output of the pilot correlator 2 is connected to an input of respective Wiener filters 4, 6, 8, and is also connected to an input of respective multipliers 10, 12, 14. Each multiplier has a further input connected to an output of a respective Wiener filter. The output of each Wiener filter is also connected to a multiplier in Figure 2 via lines A, B, C. The Wiener filters are arranged to provide an optimum estimation over a set of contiguous ranges of vehicular speeds. The output of each multiplier 10, 12, 14 is connected to a respective integrator circuit 16, 18, 20. The output of each integrator is connected to a respective scaling circuit 22, 24, 26. The scaling circuits are employed to provide the weighted filter selection metrics to be described later. The outputs of the scaling circuits are connected to a selection device 28 which analyses the signals and selects the larger of the three signals which is to be used to maintain communication between the fixed and mobile units. The signal generated at the output of the selection device 28 is used to select which output data buffer (Figure 2) is to be used.

The circuit, as shown in Figure 1, contains three filters each optimised to operate over a desired range of vehicular speeds. The filter acts as a minimum means square error filter; the mean is extended to cover a range of correlation functions as well as signal samples and therefore an overall optimum can be found. This is simply achieved by using the required weighted average

over the correlation functions applying over the range of doppler frequencies of interest.

The sets of coefficients may be conveniently derived from the following formula, which represent the Normal (or Yule-Walker) equation for determination of coefficients.

Consider the general case of a previous step estimator:

$$\hat{y}_n = \sum_{i=k_1}^{k_2} a_i . x_{n-i}$$

The one step predictor applies for $k_1 = 1$ and $k_2 = k$. The symmetrical previous step estimator applies for $k_1 = -k$ and $k_2 = k$.

The mean square error, ε is defined as:

$$\varepsilon = E\left[|y_n - \hat{y}_n|^2\right]$$

Selection of the appropriate filter will now be discussed in detail. In the context of a receiver as shown in the drawing, the complex conjugate of the filter output is multiplied by the signal sample to generate a phase and amplitude compensated sample for detection. The multipliers 10, 12 and 14 (together with the corresponding multipliers in the Q channel) carry out this function. Modulation will arbitrarily impose inversions on these compensated samples about 50% of the time. This can be handled in one of two ways. In the case of a pilot reference signal, an

independent multiplication of the pilot samples by the conjugate of the filter outputs may be employed for the purpose of filter selection. This has the advantage that there can be no decision errors affecting the filter selection process. On the other hand it is computationally wasteful since the operation does not contribute directly to data modulation. The alternative is to make hard decisions on the data and invert those compensated samples with a negative sign. The compensated samples over a frame are added together for each of the filters to generate a decision metric. Thus the metric has the form:

$$FSM_p = W_p \sum_{n=1}^{M} \hat{y}_{pn}^{*} . x_n$$

Where:

FSM_p is the Filter Selection Metric corresponding to the pth filter.

W_p is a constant weighting applied to the metric.

$\hat{y}_{pn}$ is the estimate of the nth sample of the frame from the fading process at the output of the pth filter.

M is the number of bits in a frame.

For the case of a one step predictor we can substitute for $\hat{y}_{pn}$ to obtain

$$FSM_p = M \sum_{n=1}^{k} a_{pn} . \hat{\phi}_{xx}(n)$$

where a_{pn} are the coefficients of the pth filter and

$$\hat{\phi}_{xx}(n) = \frac{1}{M}\sum_{m=1}^{M} x_{m-n}^{*} . x_m$$

and is an estimate of the auto-correlation of the received samples obtained over the frame. FSM_p is an estimate of a variable which increases as the mean square error decreases and it should make a good metric.

Although FSM_p increases as the mean square error of the filter reduces, its value does not provide an absolute indication of the effectiveness of the filter. This is because the filters used are compromise Wiener-like filters rather than being fully optimised. Thus, when using the metrics to select the best filter, some weighting is required to ensure that the crossover between filters takes place at the optimum speed. This is applied empirically through the values of W_p. For example, the values of W_p were 1, 1.09, 1.28 for a set of three particular filters optimised for the vehicular speed ranges, 0 - 100 mph, 100 - 200 mph and 200 - 300 mph respectively.

Referring to Figure 2, a data handling circuit is shown. A data input signal line 56 is connected to an input of a plurality of multipliers 32, 34, 36. A second input of each multiplier is connected to an output of a respective Wiener filter (Figure 1) via lines A, B, C. An output of each multiplier 32, 34, 36 is connected to an input of a respective limiting circuit 38, 40, 42. Each limiting

circuit has an output line connected to a respective data buffer 44, 46, 48, each of which have a data output line 50, 52, 54.

The operation of Figure 2 will now be described. The data signal on the input line 56 is applied to the multipliers 32, 34, 36. Each multiplier also receives the output signal from a respective Wiener filter 4, 6, 8 (Figure 1) via lines A, B, C. The multiplier 32, 34, 36 operate to produce an output signal which is fed to a respective limiter circuit 38, 40, 42. The output of each limiter circuit is applied to a respective data buffer 44, 46, 48, each of which provide estimates of the demodulated data on their output lines 50, 52, 54. The output of the buffer circuit which is to be used is selected by the selector circuit 28 shown in Figure 1, via known switching means (not shown).

The circuitry described so far in respect of Figures 1 and 2 correspond only to the I channel of the receiver and there will be a corresponding Q phase channel in which all the operations are replicated up to a point of summation. In Figure 1 the filters 4, 6, 8 and the multipliers 10, 12, 14 are replicated in the Q channel circuit 30, and the I and Q channel output signals are applied to the integrator circuits 16, 18, 20. In Figure 2 the multipliers 32, 34, 36 are replicated in the Q channel circuit 58, and the I and Q channel output signals are applied to the limiters 38, 40, 42.

It will be appreciated that the above description relates to one embodiment of the invention. It will be appreciated by those skilled in the art that different types of Wiener filter may be used. It will also be appreciated that more Wiener filters may be used

to give a larger number of speed ranges depending upon the application.

Furthermore, in the context of a spread spectrum receiver, Rake technology would be used and the Wiener filters would be replicated over the different Rake fingers and summed for the purposes of demodulation in the Figure 2 element, and also summed at the outputs of the different multipliers 10, 12, 14 in Figure 1 prior to accumulation and filter selection decision.

Where there is no pilot signal or where simplicity of circuitry is paramount, the replication of demodulated circuits can be avoided by having a single demodulator circuit which demodulates signals based on the output of the Wiener filter which was selected as preferred in the previous transmission frame.

CLAIMS

1. Apparatus for use in equipment providing a digital radio link between a fixed and a mobile radio unit, said apparatus comprising correlator means arranged to receive an input signal, a plurality of Wiener filters arranged to receive an output signal from the correlator means, said filters being adapted by scaling means to provide optimum estimation over a set of contiguous ranges of vehicular speed, enabling each filter to be responsive to a different range of speed of the mobile unit, and selection means for selecting which Wiener filter is used to maintain a radio link between the fixed and mobile unit in dependence upon the speed of the mobile unit.

2. Apparatus as claimed in Claim 1, wherein the output of each Wiener filter is connected to an input of a respective multiplier, each multiplier having a further input connected to the output of the correlator means, and each multiplier is arranged to generate an output signal which is applied to a respective integrator circuit arranged to generate an output signal for application to an input of the scaling means associated with each Wiener filter.

3. Apparatus as claimed in Claim 2, wherein the output from each Wiener filter is applied to a data handling circuit including a plurality of multipliers, each of which receives the output signal from a respective one of the Wiener filters and a data signal, and each multiplier is arranged to generate an output signal which is

stored in data storage means, and data output therefrom is controlled by said selection means.

4. Apparatus as claimed in Claim 1, 2 or 3, wherein the correlator means is a pilot correlator.

5. Apparatus as claimed in Claim 4, wherein for the purpose of filter selection, an independent multiplication of pilot samples by the conjugate of the filter outputs is employed.

6. Apparatus as claimed in Claim 4, wherein the selection of an appropriate filter is determined by use of a decision metric.

7. Apparatus as claimed in Claim 1, wherein the apparatus is used in a spread spectrum receiver and the Wiener filters are replicated over different Rake fingers.

8. Apparatus as claimed in Claim 1, 2 or 3, wherein a single demodulator circuit is arranged to operate on signals spaced on the output of the Wiener filter selected as optimum in the previous transmission frame.

9. Apparatus substantially as hereinbefore described with reference to the accompanying drawing.

Patents Act 1977
E› niner's report to the Comptroller under Section 17 (The Search Report) -12-

Application number

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Relevant Technical fields

(i) UK Cl (Edition L) H4L - LDC; H4P - (PAL,PAN,PAQ)

(ii) Int Cl (Edition 5) H04L - 27/38

Databases (see over)

(i) UK Patent Office

(ii) ONLINE WPI

Search Examiner

S. J. DAVIES

Date of Search

27 MAY 1993

Documents considered relevant following a search in respect of claims 1 - 9

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	WO 91/20142 (MOTOROLA) (the whole document)	

Category	Identity of document and relevant passages -13-	Relevant to claim(s)

Categories of documents

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